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Research and Development Report

Infrared Implications in Double Hull Surface Ship Design

by

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Infrared Implications in Double Hull Surface Ship Design

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Results from this analysis are used as input to the Ship Infrared Electro-Optical Scenario (SIREOS) computer program to provide thermal predictions for the various designs considered. It is found that a noninsulated double hull ship is approximately equivalent to a single hull with 1-in. inside insulation. A wet double hull, whether full of water or fuel or subjected to a continuous flow of fluid over the interior surface of the outside skin, appears to provide significant IR benefits through the elimination of localized "hot spots." Practical recommendations are presented that may be helpful during the design phase of a ship that features a double hull variant.

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ABSTRACT

A conceptual design for a double hull, no-frame structure of a typical Navy ship is studied to estimate the infrared radiation that originates from such a hull. In order to compare various double hull configurations, a candidate hull section is modeled. In particular, the geometry (spacing between hulls, plate thicknesses, etc.) and thermal parameters (insulating techniques, solar loading and convective cooling, thermal capacitance, etc.) are evaluated.

Results from this analysis are used as input to the Ship Infrared Electo-Optical Scenario (SIREOS) computer program to provide thermal predictions for the various designs considered. It is found that a non-insulated double hull ship is approximately equivalent of a single hull with 1-in. inside insulation. A wet double hull, whether full of water or fuel or subjected to a continuous flow of fluid over the interior surface of the outside skin, appears to provide significant IR benefits through the elimination of localized "hot spots." Practical recommendations are presented that may be helpful during the design phase of a ship that features a double hull variant.

ADMINISTRATIVE INFORMATION

The analysis effort described herein was sponsored by the Office of the Chief of Naval Research (OCNR Code 33) under the Advanced Double Hull Technology Project (RH21S11). The work was performed in the Signatures Directorate (Code 7230) at the Carderock Division of the Naval Surface Warfare Center (CDNSWC).

INTRODUCTION

The Carderock Division of the Naval Surface Warfare Center (CDNSWC) is investigating the use of a double hull, no-frame structure for mid-sized surface combatants as well as logistic and amphibious support ships. The double hull concept consists of an inner and outer plate structure that wraps around the bottom and side shell up to the strength deck. Transverse frames are eliminated. The two plates that represent the skins are connected by longitudinal web girders, forming a cellular structure. The relative advantages of such a double hull structure are documented by the work of Sikora et al.* The present report presents the results of a study that quantifies the infrared (IR) impact of a double hull surface ship. In addition, several double hull designs are

* Sikora, J., P.A. Silvia, and N.S. Nappi, Sr., "Whole Ship Effects and Producibility Approaches for Double Hull Ships," David Taylor Research Center Report SSPD-90-173-7 (Oct 1989).

suggested that, if implemented, could further reduce the IR radiation of the ship by reducing the contrast between ship and background and by eliminating potential "hot spots" on the external skin.

APPROACH

The objective of the study is to determine the potential impact of a double hull design on the infrared contrast radiation of a ship when compared to the case of a conventional single hull design. To make this comparison, representative sections of both single and double hulls are geometrically modeled. The single hull model assumes a skin patch 27 in. by 96 in. with a hull thickness of 0.31 in. These assumptions are based on typical ship stringer and frame spacing. The physical geometry of the double hull varies depending on fore/aft location and distance above the waterline.* For this study, it is assumed that the double hull skin spacing and web spacing is 27 in. The skin thicknesses are 0.25 in. and 0.31 in. for the inside and outside skins, respectively. The fore/aft length of the model is assumed to be 12 in. In essence, the double hull area evaluated is a patch 27 in. by 12 in; see Fig. 1.

Based on this geometry and using a thermal network approach, models were developed for both single and double hull configurations. These configurations allow the evaluation of hull patch skin temperatures for various insulation schemes and varying environmental conditions.

Infrared characteristics of particular interest are (1) the thermal behavior of the average hull skin temperature as compared to the background, and (2) the change in skin temperature due to large variations in compartment temperature. This change reflects the sensitivity of the hull thermal system to the compartment temperature and the potential for developing "hot spots" on the skin. In ship IR terminology, "hot spots" refer to small areas of the outer skin that develop higher temperatures than their immediate surroundings. In this study, both the increase in average outer skin temperature as well as the appearance of local maxima are examined.

Following a direct single hull, double hull comparison, several double hull variants were conceptually developed that have the potential for further IR improvements. One such variant, a wet double hull is modeled and analyzed in detail. This variant assumes that the space between the skins is filled with water or that the inner surface of the outer skin is covered with a layer of water. (Other fluids are also potential candidates.) Contrast is minimized by assuming that the water temperature is equal to the apparent temperature of the background. In both cases, the water is circulated through the space to maintain a constant temperature. In principle, this concept allows excellent heat transfer between the outside skin and the water (high convective film coefficient) while providing a large thermal mass. The net effect is a hull temperature approximately equal to the water (background) temperature with minimal skin thermal gradients.

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* Sikora, Silvia, and Nappi, op cit.

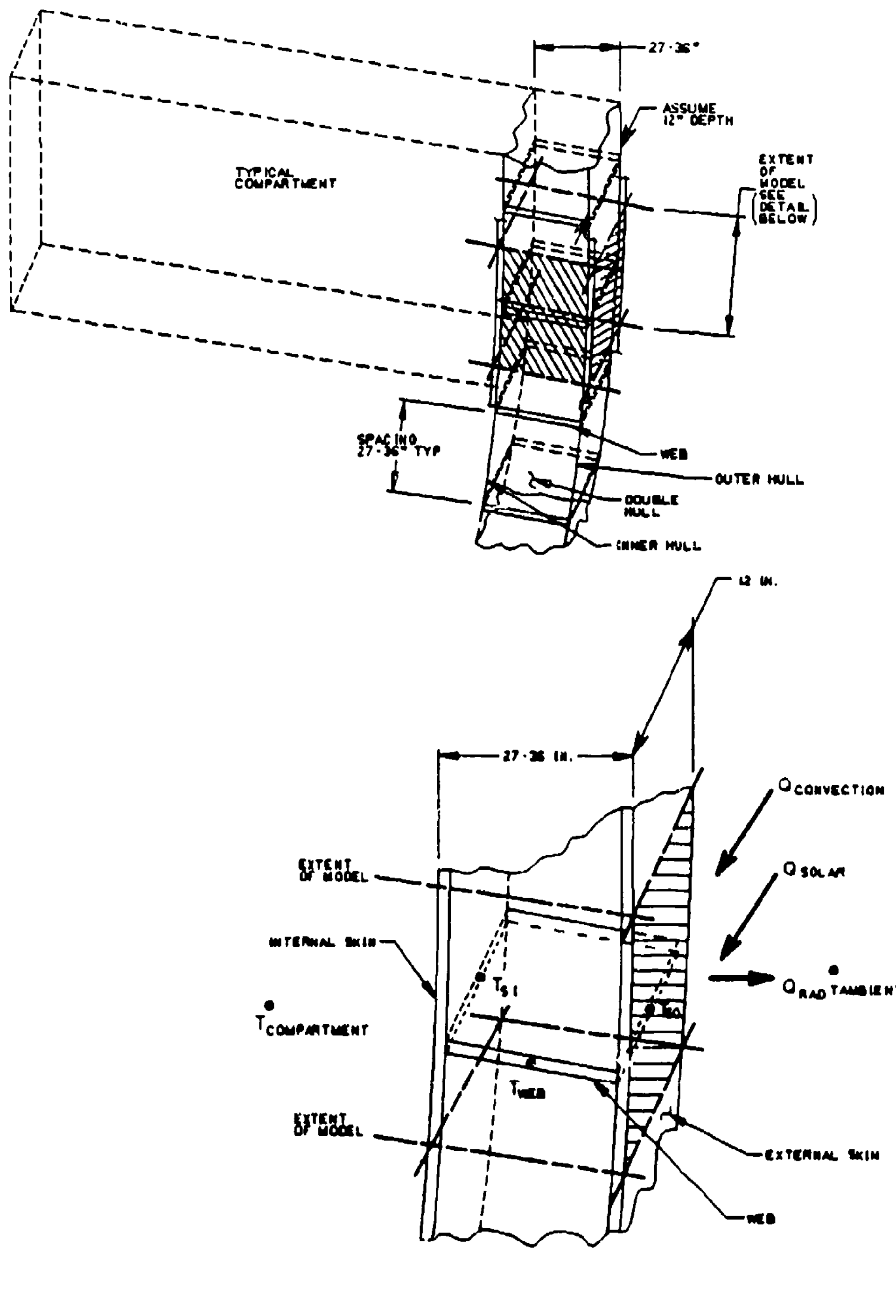

Fig. 1. Double hull design.

The models (single hull, double hull, and double hull variant) were then used to calculate the overall coefficients of heat transfer U needed by the SIREOS computer program to perform the parametric analysis. Selected computer runs provided valuable detailed insight into the effectiveness of the various hull designs considered.

ANALYSES AND RESULTS

For comparison purposes, the models were coded into a computer spreadsheet. Typical printouts of parameters used for single and double null models are presented in Appendix A. By varying parameters such as hull thicknesses, double hull spacing, insulation thickness, compartment temperatures and environmental conditions, parametric results for the hull skin temperature and the overall coefficient of heat transfer were obtained. Assumptions common to all of the analyses are listed in Table 1.

Table 1. Parameter assumptions.

Parameter	Value	Equivalent °F Temperatures
Solar load	274 W/m^2 (86.8 Btu/hr-ft^2)	
Wind speed	15 knots (25 ft/sec)	
Compartment Temperature	21.1/32.2°C	70/90°F
Air Temperature North Atlantic Summer Weather	10.3°C	50.5°F
Air Temperature North Atlantic Winter Weather	3.8°C	38.8°F
Air Temperature Mediterranean Summer Weather	24.8°C	76.6°F
Air Temperature Mediterranean Winter Weather	15.8°C	60.4°F

Results of the analyses are summarized in Table 2. Note that a double hull with no insulation produces an improved overall coefficient of heat transfer when compared to a noninsulated single hull (U= 0.95 to 1.54 versus 2.70 to 4.40, respectively). The U values give insight into the sensitivity of the skin temperature to the compartment temperature of the ship; the high U values indicate increased sensitivity. Through interpolation of the results, the noninsulated double hull is determined to be as effective as

Table 2. IR evaluation matrix for a double hull.

CONDITIONS		GEOMETRIC CONFIGURATION					
		SINGLE HULL		DOUBLE HULL			
		2-in. Insulation	No Insulation	No Insulation	1-in. Insulation on Inside Skin	Non-circulating Fluid in Space	Circulating Fluid in Space
DAY	North Atlantic Summer	Hi Skin Temp (ΔT = 15 F) No Hot Spots (ΔT = 0.5°F)	Hi Skin Temp Hot Spots (0.8 to 2.5°F)	Hi Skin Temp (15°F) No Hot Spots (0.6 to 1.0°F)	Hi Skin Temp No Hot Spots (0.3 to 0.5°F)	Lo Skin Temp No Hot Spots	Lo Skin Temp No Hot Spots
	North Atlantic Winter	Hi Skin Temp No Hot Spots	Hi Skin Temp Hot Spots	Hi Skin Temp No Hot Spots	Hi Skin Temp No Hot Spots	Lo Skin Temp No Hot Spots	Lo Skin Temp No Hot Spots
	Mediterranean Summer	Hi Skin Temp No Hot Spots	Hi Skin Temp Hot Spots	Hi Skin Temp No Hot Spots	Hi Skin Temp No Hot Spots	Lo Skin Temp No Hot Spots	Lo Skin Temp No Hot Spots
	Mediterranean Winter	Hi Skin Temp No Hot Spots	Hi Skin Temp Hot Spots	Hi Skin Temp No Hot Spots	Hi Skin Temp No Hot Spots	Lo Skin Temp No Hot Spots	Lo Skin Temp No Hot Spots
NIGHT	North Atlantic Summer	Lo Skin Temp (ΔT = 0.5 to 1.0 °F) No Hot Spots	Lo Skin Temp Hot Spots	Lo Skin Temp (0.8 to 1.8°F) No Hot Spots	Lo Skin Temp No Hot Spots	Lo Skin Temp No Hot Spots	Lo Skin Temp No Hot Spots
	North Atlantic Winter	Lo Skin Temp No Hot Spots	Lo Skin Temp Hot Spots	Lo Skin Temp No Hot Spots	Lo Skin Temp No Hot Spots	Lo Skin Temp No Hot Spots	Lo Skin Temp No Hot Spots
	Mediterranean Summer	Lo Skin Temp No Hot Spots	Lo Skin Temp Hot Spots	Lo Skin Temp No Hot Spots	Lo Skin Temp No Hot Spots	Lo Skin Temp No Hot Spots	Lo Skin Temp No Hot Spots
	Mediterranean Winter	Lo Skin Temp No Hot Spots	Lo Skin Temp Hot Spots	Lo Skin Temp No Hot Spots	Lo Skin Temp No Hot Spots	Lo Skin Temp No Hot Spots	Lo Skin Temp No Hot Spots
Overall Heat Transfer Coefficient		U = 0.78/1.00	U = 2.70/4.40	U = 0.95/1.54	U = 0.55/0.73	U approx. = 90 Water warmup = 0.1°F/hr approx; No internal convection	Water Air perfomance is unsatisfactory

NOTES:

1. Ship speed is 15 knots.
2. Compartment temperature is 70°F (21.1°C) minimum and 90°F (32.2°C) maximum.
3. Hi and Lo Skin Temp compares relative ΔT between Hull Skin Temp and environment.
4. Overall coefficient of heat transfer U is in W/m^2-°C.

a single hull with one inch of insulation. A comparison of the noninsulated and insulated double hulls reveals similar trends. Both configurations experience high average skin surface temperatures during the day (compared to the background temperature) due to solar heating, and there are no "hot spots." ("Hot spots" result from unsatisfactory temperature gradients on the hull, the major cause of which is the sensitivity of the hull outer skin to the temperature inside the adjacent ship compartment.)

Both wet double hull cases (where the fluid is kept either stagnant or in circulation) produce excellent results. A noteworthy assumption is that the water temperature is equal to the sea surface temperature. Significant heat transfer occurs in these cases between skin and water which reduces high skin temperatures even during the day, and prevents the formation of "hot spots." In addition, a U value of 90 Watts/m^2-°C listed for the wet double hull does not include the compartment film coefficient, since the water inside the double hull acts as a thermal insulator and thermal mass. Furthermore, the circulating air in lieu of water will not achieve the same level of improvement because of its low thermal mass and the inability to effectively remove sufficient amounts of heat from the external skin of the hull during the day.

ANALYSIS USING THE SIREOS COMPUTER PROGRAM

The parametric analysis provides input to the SIREOS (Ship Infra-Red/Electro-Optical Scenario) computer program.* The software uses a detailed geometry description of a ship made up of a number of triangular elements. Inclusion of weather, location, sun position, and ship trajectory information allows the computation of a radiance map of the scene in a given infrared spectral band. Both atmospheric path radiance as well as attenuation effects are included. The results of this analysis are contained in Appendix B. Because the interest in this report focuses on the hull, there are no stacks, mast, or superstructure included in the geometry.

The computer program results confirm that no discernible improvement can be observed with a dry double hull, but significant improvement is achieved with a wet double hull. When comparing single and dry double hulls, the dry double hull is assumed not to be insulated; whereas, the single hull is covered with 1 or 2 inches of insulation.

Figure 2 displays three computed images in false coloring, all assuming North Atlantic summer weather and the LWIR band. The image in Fig. 2a is of the single hull, while in Figs. 2b and 2c the images are of the double huli (dry) and the wet double hull, respectively. The water that fills the interior of the wet double hull is maintained at sea surface temperature.

* Burns, R.H., R.C. Brown, R.F. Higby, F.J. Mueller and R.F. Wancowicz, "Description of the Ship Infrared/Electro-Optical Scenario (SIREOS) Computer Model, Report No. 1," David W. Taylor Naval Ship R&D Center Report DTNSRDC-80/097 (Nov 1980).

RECOMMENDATIONS

The analysis indicates that a double hull concept has the most desirable features from the thermal point of view. Insulating schemes alone do not appear to provide the major gains that are possible with the wet double hull. Future tasks that may further understanding of the problem include:

- Evaluation of the overall coefficient of heat transfer U for an uninsulated single hull as a function of compartment ventilation characteristics. Such an evaluation should add credence to the results of the present study.

- Design and construction of a multi-purpose test platform having a double hull configuration. The test platform would be used to determine the effects of changing environmental conditions, insulation, compartment temperature and temperature of the water in the double hull, on the outside skin temperature of the hull.

- Such a test platform can be an IR physical scale model and measurements can be performed under totally repeatable laboratory conditions.*

- Analysis of the empirical results for use as input to an IR prediction program.

- For the purpose of extending the empirical results, development of a much wider matrix of possible ship operational conditions that are to be investigated with the help of an IR program.

CONCLUSIONS

From a thermal point of view, the basic noninsulated double hull is approximately equivalent to a single hull with 1 in. of inside insulation. Using a double hull thereby reduces or potentially eliminates the need for further hull insulation. Even in areas where insulation might still be required, the flat interior surface that a double hull provides, reduces installation complexity and allows a significant reduction in installation costs. Variants such as the wet double hull, whether fully filled with water/fuel or subjected to a continuous flow of conditioning water over the interior surface of the outside skin, appear to provide significant IR benefits.

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* Cervenka, P.O. and L. Massa, "Laws of Infrared Similitude," CDNSWC Report CARDIVNSWC-TR-94/002 (Jan 1994).

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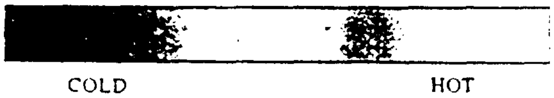

Fig 2a. Single skin hull.

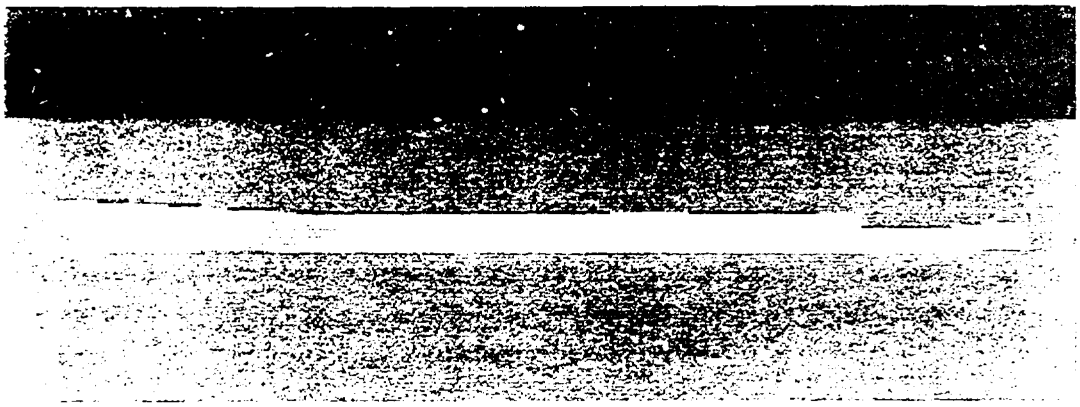

Fig. 2b. Double hull dry skin.

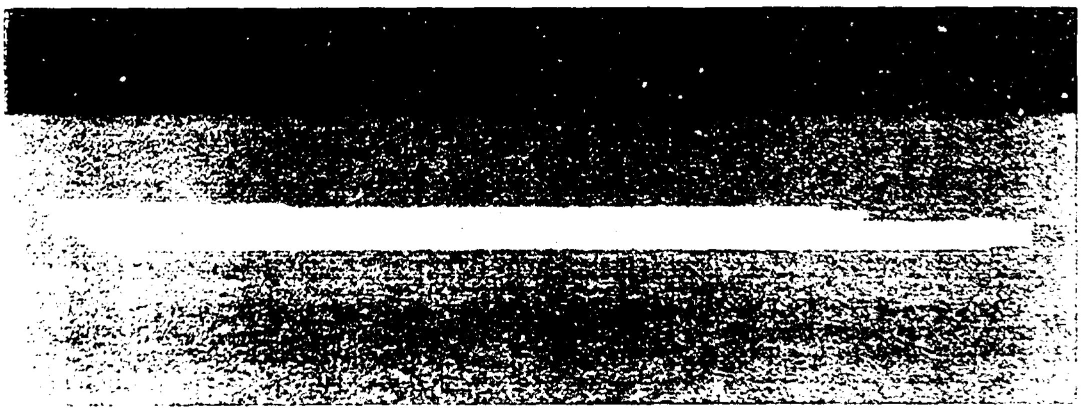

Fig. 2c. Wet double hull.

Fig. 2. Computed LWIR images of a surface ship on a North Atlantic summer afternoon.

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APPENDIX A

PARAMETERS USED IN SINGLE AND DOUBLE HULL SKIN TEMPERATURE CALCULATIONS

SINGLE HULL

Thermal properties at approximately 100°F

Air thermal conductivity, Btu/hr-ft-°F	0.02
Air specific heat, Btu/lb-°F	0.24
Air density, lb/ft^3	0.07
Air viscosity, (lb mass)/hr-ft	0.05
Thermal conductivity of steel, Btu/hr-ft-°F	26.00
Thermal conductivity hull insulation, Btu/hr-ft-°F	0.02

Model Dimensions

Hull outside skin thickness, in.	0.31
Frame spacing, in.	96.00
Stringer spacing, in.	27.00
Frame thickness, in.	0.50
Frame depth, in.	12.00
Stringer skin thickness, in.	0.31
Stringer depth, in.	8.00
Insulation thickness (hull), in.	2.00
Insulation thickness (stringer), in.	2.00
Insulation thickness (frame), in.	2.00

Solar Flux Incident on Hull Surface

Direct solar flux, Btu/hr-ft^2	202.00
Diffuse solar flux, Btu/hr-ft^2	36.00
Reflected solar irradiance, Btu/hr-ft^2	10.10
In band surface solar absorptivity, α	0.35
Surface emissivity, ϵ	0.95
Total solar heat flux, Btu/hr-ft^2	86.83

Wind Velocity and Environmental Temperatures

Wind velocity, knots	15.00
Compartment temperature, °F	70.00
Background temperature, °F	76.64

Calculated Hull Skin Temperature

Skin temperature, °F	90.20

DOUBLE HULL

Thermal Properties at Approximately 100°F

Air thermal conductivity, Btu/hr-ft^2°F	0.02
Air specific heat, Btu/lb-°F	0.24
Air density, lb/ft^3	0.07
Air viscosity, (lb mass)/hr-ft	0.05
Thermal conductivity of steel, Btu/hr-ft-°F	26.00
Thermal conductivity of insulation (hull), Btu/hr-ft-°F	0.02
Thermal conductivity of insulation (compartment), Btu/hr-ft-°F	0.02

Model Dimensions

Hull outside skin thickness, in.	0.31
Hull length, in.	12.00
Double hull spacing, in.	27.00
Hull inside skin thickness, in.	0.25
Web skin thickness, in.	0.25
Web length, in.	12.00
Web depth, in.	27.00
Insulation thickness (space-outside skin), in.	0.00
Insulation thickness (space-inside skin), in.	0.00
Insulation thickness (space-web surface), in.	0.00
Insulation thickness (interior compartment), in.	1.00

Solar Flux Incident on Hull Surface

Direct solar flux, Btu/hr-ft^2	202.00
Diffuse solar flux, Btu/hr-ft^2	36.00
Reflected solar irradiance, Btu/hr-ft^2	10.10
In band surface solar absorptivity, α	0.35
Surface emissivity, ϵ	0.95
Total solar heat flux, Btu/hr-ft^2	86.83

Wind Velocity and Environmental Temperatures

Wind velocity, knots	15.00
Compartment temperature, °F	70.00
Background temperature, °F	76.64

Calculated Hull Skin and Inside Temperatures

Skin Temperature, °F	90.30
Hull Temperature, °F	76.69
Hull Inside Temperature, °F	87.21
Hull Outside Temperature, °F	92.95
Space Temperature, °F	90.08
Web Temperature, °F	90.08

APPENDIX B

SIREOS PROGRAM RUNS

WEATHER PARAMETERS

The climactic conditions and parameters input to the SIREOS computer program include:

North Atlantic Summer Weather Conditions

Air temperature	52.0°F
Water temperature	52.3°F
Cloud cover	86 %
Meteorological (visible) range	21.3 km
Wind velocity	12.5 ft/sec

Eastern Mediterranean Summer Weather Conditions

Air temperature	78.8°F
Water temperature	78.6°F
Cloud cover	0 %
Meteorological (visible) range	38.9 km
Wind velocity	9.1 ft/sec

Note that the North Atlantic weather conditions assumed in these computer runs are characterized by a high cloud cover (86 %) and low temperatures. This is in direct contrast to the cloudless sky (0 %) and warm temperatures of the Eastern Mediterranean. The calculations are carried out with the intention of simulating two time periods: 1000 and 1400 hours. The target ship is assumed to be moving along a 270-deg direction during the entirety of the runs. The sensing system is positioned 0.5 km off the port side of the vessel at an altitude of 100 ft above the surface of the sea. The computations are descriptive of both infrared atmospheric windows; namely, the 3 to 5 and 8 to 12 micrometer bands.

HULL GEOMETRY

The computer runs presented apply to the four ship hull types evaluated:

- Conventional single skin hull,
- Double skin hull, and
- Two double skin hulls with water between the skins.

A generic ship type was used that is made up of a superstructure and a single skin hull model. A single superstructure was used throughout the computation. To determine the relative contribution of the superstructure to the total contrast, the thermal contribution of the superstructure was calculated.

To model the double skin hull, the conduction coefficients of the single skin hull were modified. The heat capacity terms remain the same because of the approximately equal weights of the hull for both single and double skins. For modeling convenience, the entire hull is assumed to be double skinned. In an actual implementation, however, single skinned end sections would exist at both ends of the hull.

SINGLE SKIN HULLS

The single skin hull is described by three conduction coefficients that correspond to:

- no insulation
- 1-in. insulation
- 2-in. insulation

The analysis indicates that the conduction coefficient of the double hull with no insulation is about the equivalent to a single skin hull with 1-in. insulation. Hence, in places where the single skin hull has either no insulation or 1-in. insulation, a double hull has been modeled with no insulation.

DOUBLE SKIN HULLS

The double hull with 1-in. insulation corresponds to the single hull with 2-in. insulation. The appropriate conduction coefficients used in the SIREOS runs are obtained from the parametric analysis. A ship built according to the scheme described should be more cost-effective due to lower insulation requirements.

A double skin hull that uses water between the skins is referred to as a wet double hull. The conduction coefficients and heat capacity values used in the SIREOS model for the wet double hull are calculated for a hull having a 27-in. spacing between shells. The conduction coefficients and heat capacity values are the same for both wet double hull designs. The difference between the wet double hull models is in the temperature of the compartments. The SIREOS computer program is not designed to accept a shell temperature input. Initially, the code assigns the shell the same temperature as that of the compartment behind it.

Assigning the same temperature to each wet double hull poses a problem in that the initial temperature condition for the water between the shells should be equal to the sea surface temperature. With the shell temperatures equal to the warmer compartment temperatures, SIREOS will over-predict the contrast of wet double hulls in areas with cool water temperatures, such as the North Atlantic where the sea temperature is 52°F. Similarly, with the shell and compartment temperatures set at the cooler sea water temperatures, the heat conduction from the compartments to the shell is probably incorrect and in the wrong direction.

Runs were performed to simulate normal ship operating temperatures. Other runs were performed to describe a compartment and shell having a temperature equal to the sea surface water temperature.

ANALYSIS RESULTS

The single hull case shows only a slight reduction in overall signature contrast radiance compared to the double hull case. Only a small difference is evident because the conduction coefficients in the two cases are very similar. The images seem to show some reduction in the occurrence of hot spots, but a careful analysis of the individual scatterer contrast radiance should be done before making this decision final.

The wet double hull (sea water temperature) shows a decrease in overall contrast radiance. This largely is due to the compartment and skin temperatures being held at the water surface temperature. The wet double hull (compartment temperature) runs show the heat transfer rates and the temperature rise of the water between the shells, and were used to assess the validity of the contrast radiance signature calculated for the wet double hull (sea water temperature). The rise in temperature of the shell and water is found to be relatively small.

With the passage of time, the water temperature inside the double hull tends to be close to the sea surface temperature, indicating that the wet double hull (sea water temperature) case is a valid approximation of the signature contrast radiance for a wet double hull. An analysis of the THERMX module of SIREOS performed for a randomly chosen element (element 2) for the wet double hull (compartment temperature) case produced the following data:

Sun load	486 W/m^2
Target self-emission	-346
Contribution due to conduction	109
Contribution due to convection	-59
Total contribution into shell	190 W/m^2
Heat capacity	825 W-hr/m^2-K
Temperature rise	190/825 = 0.23 K/hr = 0.41°F/hr

After a 6-hr period, the temperature common to both water and shell rises to 53.6°F, which is 1.6°F above the 52°F sea water temperature. The corresponding temperature rise is 1.6°F/6 hr or 0.27°C/hr.

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